Heinrich Hertz

The last great physicist of the era before the discovery of X-rays, radioactivity and subatomic particles, he is best remembered for his demonstration of the connection between electromagnetism and light

by Philip and Emily Morrison

We celebrate this year the hundredth anniversary of the birth of Heinrich Rudolf Hertz, born February 22, 1857, in Hamburg. In his tragically short life of 37 years this brilliant, gentle man brought the era of "classical" physics to a glorious culmination. It was his insight into the meaning of the Maxwell theory of electricity and magnetism, leading to his discovery of radio waves, that opened up the great spectrum of waves other than light, which has been explored so rewardingly by physics and exploited in a thousand ways by modern technology. Hertz mounted to the great divide in physics, but of the new world on the other side he got only a Pisgah view—a mere glimpse of the Promised Land. He was the first to observe the phenomenon of the photoelectric effect, but he could not recognize what it meant. Hertz died on the very eve of the birth of modern physics. The discoveries of X-rays, radioactivity and the electron came within three years after his death.

HERTZ was born in 1857 and died only 37 years later. He was a student of Hermann von Helmholtz at the University of Berlin, and himself worked at Kiel, Karlsruhe and Bonn.

The intellectual climate in which young Hertz was born has been portrayed for us, in all its expansive vigor, by Thomas Mann's novels. Like Hanno Buddenbrook, the last of that close-knit family, Hertz was the son of a senator of a great Hanseatic city. He went to *Realschule* in Hamburg, and we can imagine him, like Hanno in Lübeck 40 miles away, struggling with Ovid and oppressed by the fetid air of the chemistry hall. Hertz, however, was a bright student: he became fluent in Greek and even tried Arabic. Fond of working at bench and lathe and of building instruments, living in the blossoming time of the machine industry, young Hertz felt impelled to a career as an engineer, but as his schooling advanced he came to the sure conclusion that he could be happy only in science. He wrote of his decision to his parents: "All else seemed hollow and unsatisfying." The young man went to study at the University of Munich and in the fall of 1878 enrolled in the University of Berlin, then perhaps the center of science on the Continent. There he became a student of the great Hermann von Helmholtz.

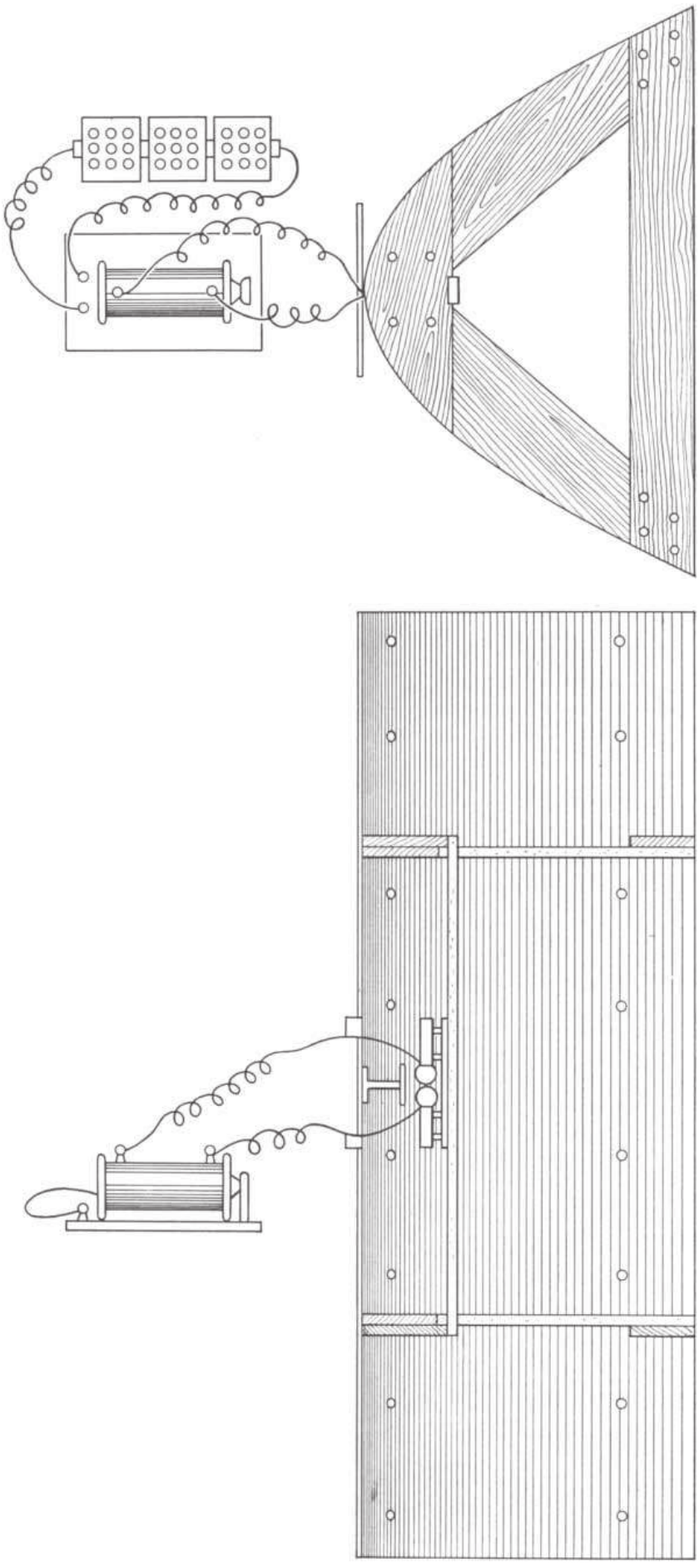
He won the master's attention at once. Helmholtz wrote: "I saw here that I had to deal with a pupil of quite unusual talent; and when . . . it fell to me to propound to the students a subject of physical research for a prize, I chose one in electromagnetics in the belief that Hertz would feel an interest in it, and would attack it, as he did, with success." Hertz's paper, entitled "Experiments to Determine an Upper Limit to the Kinetic

Energy of an Electric Current," was awarded the prize, with high commendation. (He wrote to his family that he chose to receive the gold medal instead of a cash prize and was disappointed to find that it bore no inscription to indicate that it came from the University.) Hertz received his doctoral degree *magna cum laude*, a rare distinction at Berlin in those days, and Helmholtz then made him his assistant and demonstrator.

Hertz became immersed in research on many problems, experimental and theoretical. His first few papers dealt with the behavior of oscillating electric currents. Then he carried out a couple of elegant studies on hardness as a mechanical property and on the elasticity of solids; the latter paper is still a major achievement in this refractory branch of physics. Curiosity about the collisions between ice blocks on the river in deep winter led him to a theoretical study in mechanics; investigations of evaporation drew him into work on vacuums and the cathode discharge.

Hertz kept his parents informed about his work and experiments. On devising a new hygrometer, he wrote his family a lengthy letter concluding: "I may here give a little calculation which will show father how the air in the morning-room should be kept moist. . . . This has become quite a long lecture, and the postage of the letter will ruin me; but what wouldn't a man do to keep his dear parents and brothers and sister from complete desiccation?" He described to his family in detail how he built a storage battery of 1,000 small cells, "working away just like a mechanic," and how he blew glass tubes for gas-discharge experiments to save time and expense: "My impatience will not allow me to order from the glass blower today a tube which would not be ready until several days later, so I prefer to restrict myself to what can be achieved by my own slight skill at the art."

In 1883 Hertz left Helmholtz's laboratory to step up to the traditional first rung of the academic ladder in German universities: he was appointed *Privatdocent* at the minor University of Kiel. Kiel was not very well equipped, and Hertz did his best to continue his work by setting up a laboratory in his own home. Two years later, at 28, he was called to the Technische Hochschule at Karlsruhe as professor of physics. There, in the green month of April, he met Elizabeth Doll, a professor's daughter, and after a whirlwind courtship they were married in July. In beautiful Karls-



HERTZ'S APPARATUS to generate and focus electromagnetic waves is shown from above (*top*) and from the side (*bottom*). It produced waves about two feet from crest to crest.

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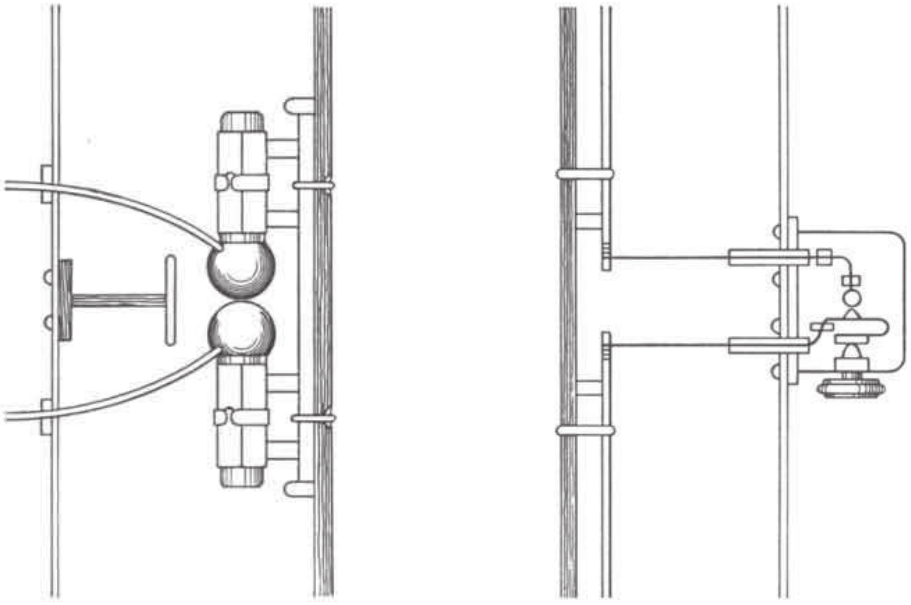


HERTZIAN WAVES were transmitted by a rod interrupted with a spark gap between two large knobs (*left*). The waves were received by another interrupted rod (*right*). The spark gap of the second rod was between the small sphere and point which appear at the far right.

ruhe, with his personal life so happily arranged, and with experimental facilities almost of the first class, Hertz began the series of electrical investigations which were to make his name immortal.

It is worthwhile to look at the physics of the time with Hertz's eyes. Mystery surrounded the transmission of electricity and magnetism. To be sure, the genius of James Clerk Maxwell had formulated a complete electromagnetic theory, summed up in compact and elegant differential equations. But the theory was difficult for the time. It was a bit like P. A. M. Dirac's theory of the spinning electron in 1932 or thereabouts—beautiful, obscure, apparently powerful but uncomfortably far at the time from any clear way to test it experimentally. Hertz wrote of Maxwell's theory: "On account of the difficulty of the theory the number of its disciples at first was necessarily small. But everyone who studied it thoroughly became an adherent, and forthwith sought diligently to test its original assumptions and its ultimate conclusions."

Its greatest adherent was young Hertz, and he set out to examine its assumptions and "ultimate conclusions" in a concrete way. The problem was to prove the existence of a relation between light and electricity. As Hertz told his lecture audiences in his wonderful popular exposition of Maxwell's theory: "I am here to support the assertion that light of every kind is itself an electrical phenomenon—the light of the sun, the light of a candle, the light of a glowworm." In our day of the ubiquitous television aerial and the radar dish, it is hard to place ourselves back in that time—when light waves seemed to have not the remotest connection with the Leyden jars and the other paraphernalia of the electrical laboratory. But on the well-laid foundations of Maxwell's equations Hertz proceeded to build a bridge between them.

His design for testing the theory was simply to generate waves by electrical means and to show that these waves would travel through the "ether" in the same way and with the same speed as light. Generation of such waves should be no great problem. It was well known that the electrical discharge from a Leyden jar was not a one-way current but a rapid oscillation. In fact, the German physicist Berend Wilhelm Feddersen had actually seen the oscillations, by viewing a spark discharge with a fast-rotating mirror which showed that the sparks jumped back and forth across the gap, clearly reversing direction a hundred thousand times per second. Hertz reasoned that such oscillations, if propagated through the "ether," ought to be detectable by a resonant receiver some distance away from the transmitting source. A receiver of the appropriate length would pick up the oscillations, and they would induce in it a current which would be signaled by the appearance of a spark across its gap.

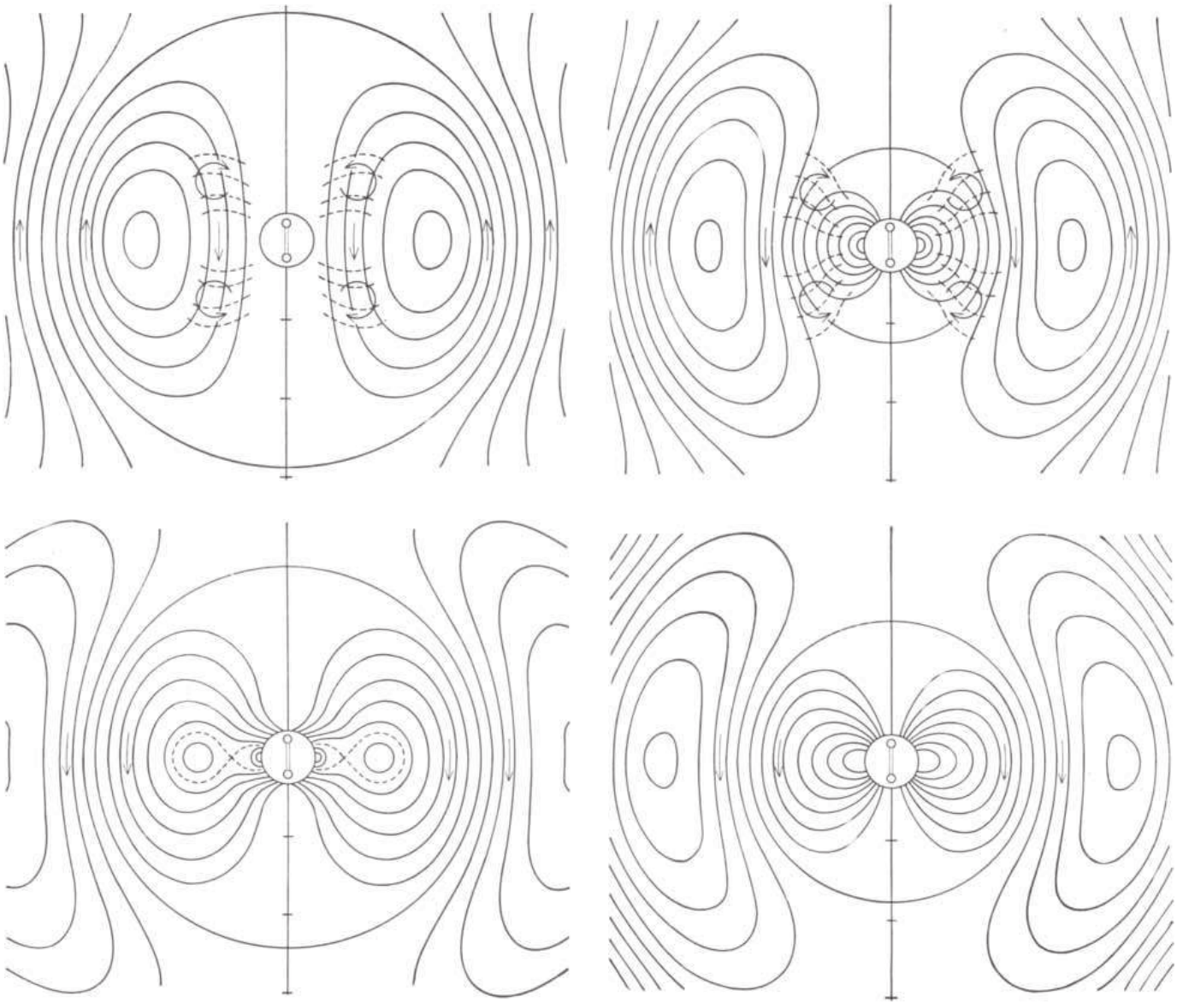
As his receiving "antenna" Hertz used a wire or brass rod a foot or so long, which meant that the waves he worked with had to be of very high frequency. He could estimate that the appropriate frequency was in the hundreds of mil-

lions of cycles per second—that is, in what we call today the microwave region. Hertz devised a simple contraption to generate these waves. In the fully developed version of his experiments he used an induction coil very like the spark coil of a Model T automobile engine to convert battery current into high-voltage pulses; these were fed by wires to a one-foot brass rod broken midway along its length by a small gap, with knobs as the poles [*see diagrams on page 100*]. The sparks produced across the gap generated current oscillations in the rod with a wavelength of about two feet (roughly double the length of the rod), which corresponds to a frequency of 500 or 600 megacycles. Some distance away from this transmitter he placed his receiver—a similar broken straight rod, with a tiny spark gap having as its two poles a little knob and a sharp point. The size of the gap was adjustable with micrometer fineness.

Hertz's first historic experiment took place in the physics lecture hall at Karlsruhe. He set up his transmitter at one end of the hall, his receiver at the other end, and in the darkened hall he glued his attention to the receiver's spark gap. And lo! tiny sparks flashed there the instant the distant transmitter was turned on. The sparks were only a few thousandths of an inch long and lasted no more than a microsecond, but the human eye is a most sensitive receiver. Hertz wrote: "In a perfectly dark room [the sparks] are visible to an eye which has been well rested in the dark."

Here, then, were electromagnetic waves other than light, traveling through the "ether" as light did. How to prove that the new waves were like light waves? Time was the essence: did these waves move with light's speed? In Hertz's laboratory, measurement of their velocity was impossible. To measure the time of travel from the transmitter to the receiver required exquisite timing with extremely sharp pulses. As Hertz remarked: "If we wish to measure a length correct to the tenth part of a millimeter, it would be absurd to indicate the beginning of it with a broad chalk line." Hertz had no oscilloscopes, no electronic tubes of any kind—in short, no means of measuring the velocity of his waves directly. Instead, he measured their wavelengths, and in this way confirmed Maxwell's calculations. Hertz made these measurements by studying the interference between direct waves and returning waves reflected from a zinc-covered wall acting as a mirror.

More convincing were his experi-



ELECTRIC FIELD around Hertz's oscillator is mapped. The second, third and fourth drawings each show the lines of force one eighth of a full period of oscillation after the preceding drawing. All the drawings in this article closely follow Hertz's originals.

Here is a cast aluminum access door for an aircraft fuel cell. Of special interest is the fact that in its flat area the thin section is held to 0.080″ ± .010″, yet it is pressure tight. Grooves for sealing gaskets are cast in to eliminate machining; the fuel cell access door is used as cast.

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ments showing that his electrical waves behaved like light waves in various contexts. He focused his waves with big mirrors of galvanized sheet; he refracted them with large prisms made of coal-tar pitch; he found that a tinfoil screen, or the body of his assistant, cast a "shadow" when placed in the path of the electrical rays. But oddly, only conducting materials cast such a shadow; insulators did not stop the ray. Hertz wrote: "It passes right through a wooden partition or door, and it is not without astonishment that one sees the sparks appear inside a closed room."

So now one had waves imperceptible to the eye, waves which found thick doors not opaque but lucid, waves scaled up hundreds of thousands of times from the wavelengths of visible light, yet waves which nonetheless obeyed laws of physical optics. All was as Maxwell had represented it: sunlight, candlelight, glowworm light and electric current were of a kind.

The importance of Hertz's work was recognized immediately. Honors poured in upon him from all over Europe. He was called in 1889, three years after his discovery, to the University of Bonn's chair of physics, made eminent by the great Rudolf Clausius, who had just vacated it by his death. Physicists began to look into the new regions of the electromagnetic spectrum which Hertz had widened so dramatically, and some of them soon foresaw practical uses for the Hertzian waves. In 1892 Sir William Crookes wrote of the possibility of communication with Hertzian waves, and Guglielmo Marconi, inspired by reading Hertz's own account of the waves, sent his first wireless messages in 1895, only nine years after Hertz's laboratory discovery. But Hertz himself, strangely enough, showed no prescience about possible uses of his waves; he even argued that they could not be of any practical use.

Hertz now entered upon experiments which fell just short of crossing into the new world of physics—the world of the electron and the atom. He had already, in fact, observed some atomic phenomena without recognizing what they meant. He had found that ultraviolet light from the transmitter's spark could touch off sparks in the receiver, but he did not realize that this was a photoelectric effect: that is, that the light initiated current in the receiver by releasing electrons from the surface of its negative pole. The electron had not yet been discovered. Hertz had come close to discovering electrons in his

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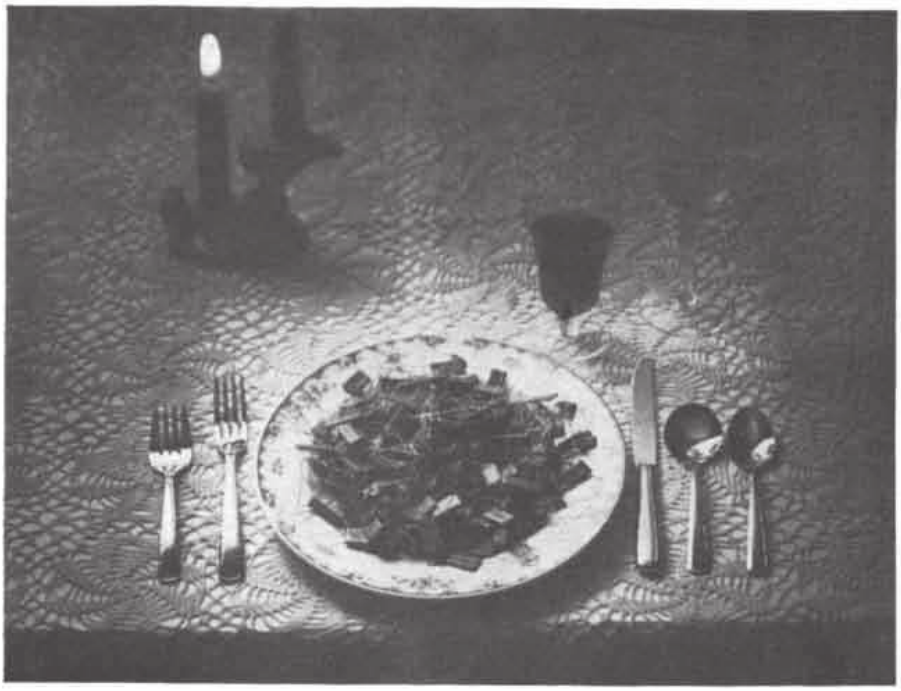

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earlier experiments with cathode rays at Berlin. Seeking to determine whether the cathode rays were electromagnetic waves or a beam of particles, he had subjected cathode rays in a vacuum to a strong electric field. If the rays were made up of charged particles, the field should deflect the beam; if they were waves, they would ignore the field. Hertz found the rays completely unaffected by the field. Unhappily his vacuum was inadequate; it contained enough residual gas to shield the rays from his electric field. J. J. Thomson, with a higher vacuum, was later to discover the electron by producing exactly the effect Hertz had sought.

At Bonn, Hertz took up again his experiments with cathode rays. He showed that the rays could pass through thin foils of metal. Had he proceeded further, he might have discovered that the emerging rays were X-rays. But this was his last experiment. Hertz, so gifted, so happy, still a young man in his prime, was cut down by cancer. An unsuccessful operation on malignant bone in 1892 left him ill and depressed; his diary bears the phrase "an unhappy time, fatigue, disgust." He gave up the laboratory and turned to theoretical work on mechanics, producing a reformulation of theory which was published after his death under the title *Principles of Mechanics*. The book bore an introduction by Helmholtz—a touching tribute by the still-living 73-year-old master to the young friend who had died at 37. Hertz's strange, cold, brilliant book on mechanics has had little influence, although it is in many ways profound and novel. But philosophers of science have lately rediscovered it, and the book has now been reprinted in English translation—the only work of Hertz available today in English.

Hertz, in pain and failing health, went on lecturing until December, 1893. He died on New Year's Day of 1894. His widow lived until 1942, and his two daughters, one a biochemist, the other a physician, are still living in Cambridge, England, where they came with their mother in 1937 when life in Nazi Germany grew intolerable for the family of a Hertz.

Heinrich Rudolf Hertz will be remembered as the last of the great classical physicists; but for the illness that allowed him only half a lifetime, he might also have been a great name in atomic physics. It is heartening to recall this gifted and engaging man—ingenious and energetic in experiment, profound in theory, philosophical in bent, amiable in every way.